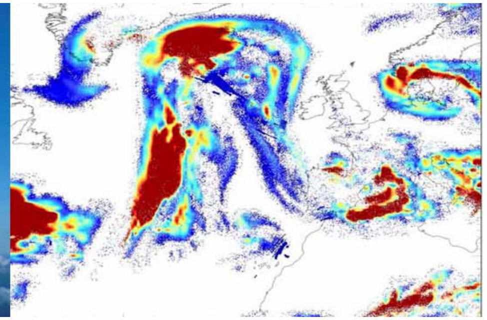
   

Are contrail cirrus climate effects predictable?

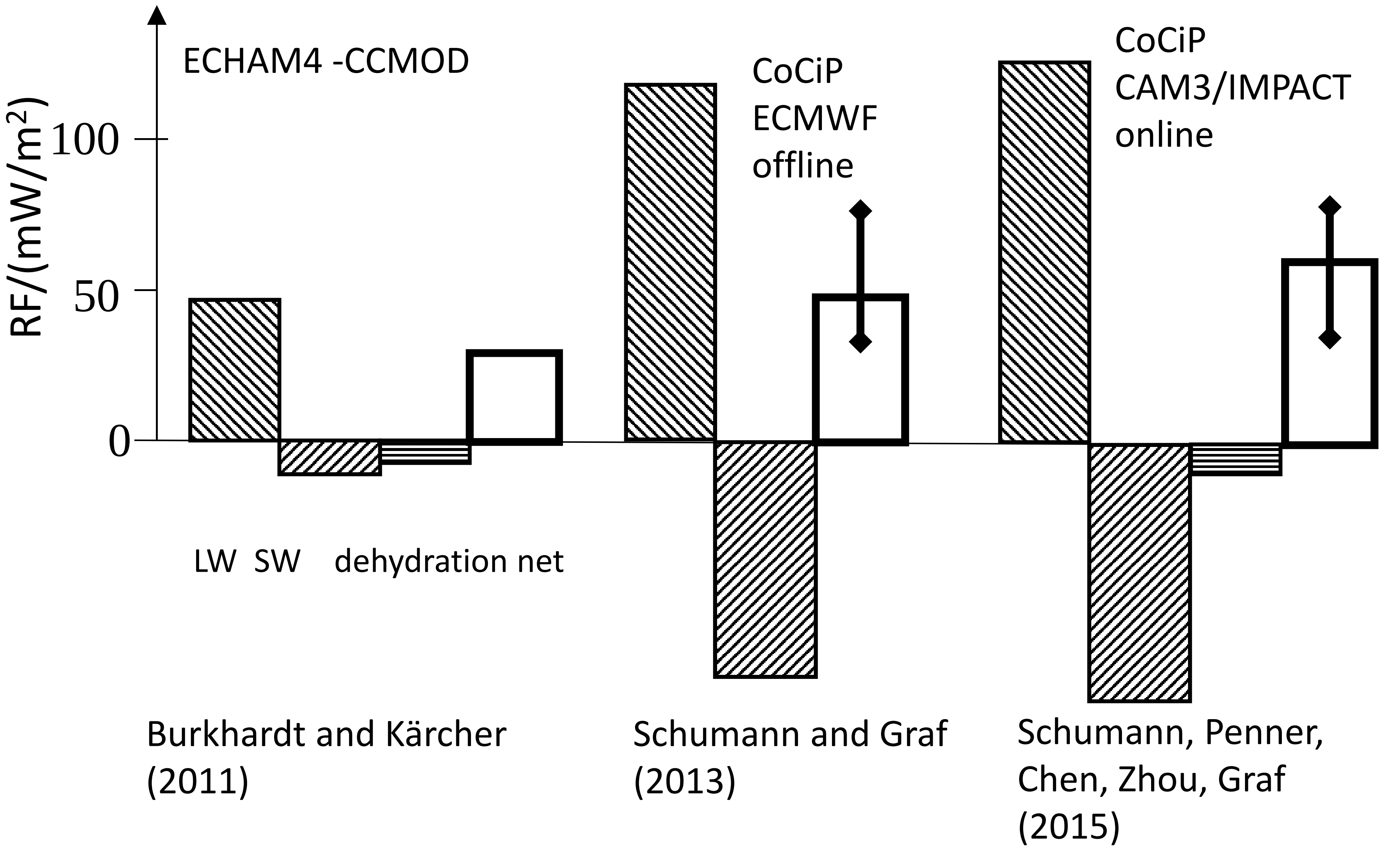
Ulrich Schumann

German Aerospace Center, Institute of Atmospheric Physics,
Oberpfaffenhofen, Germany

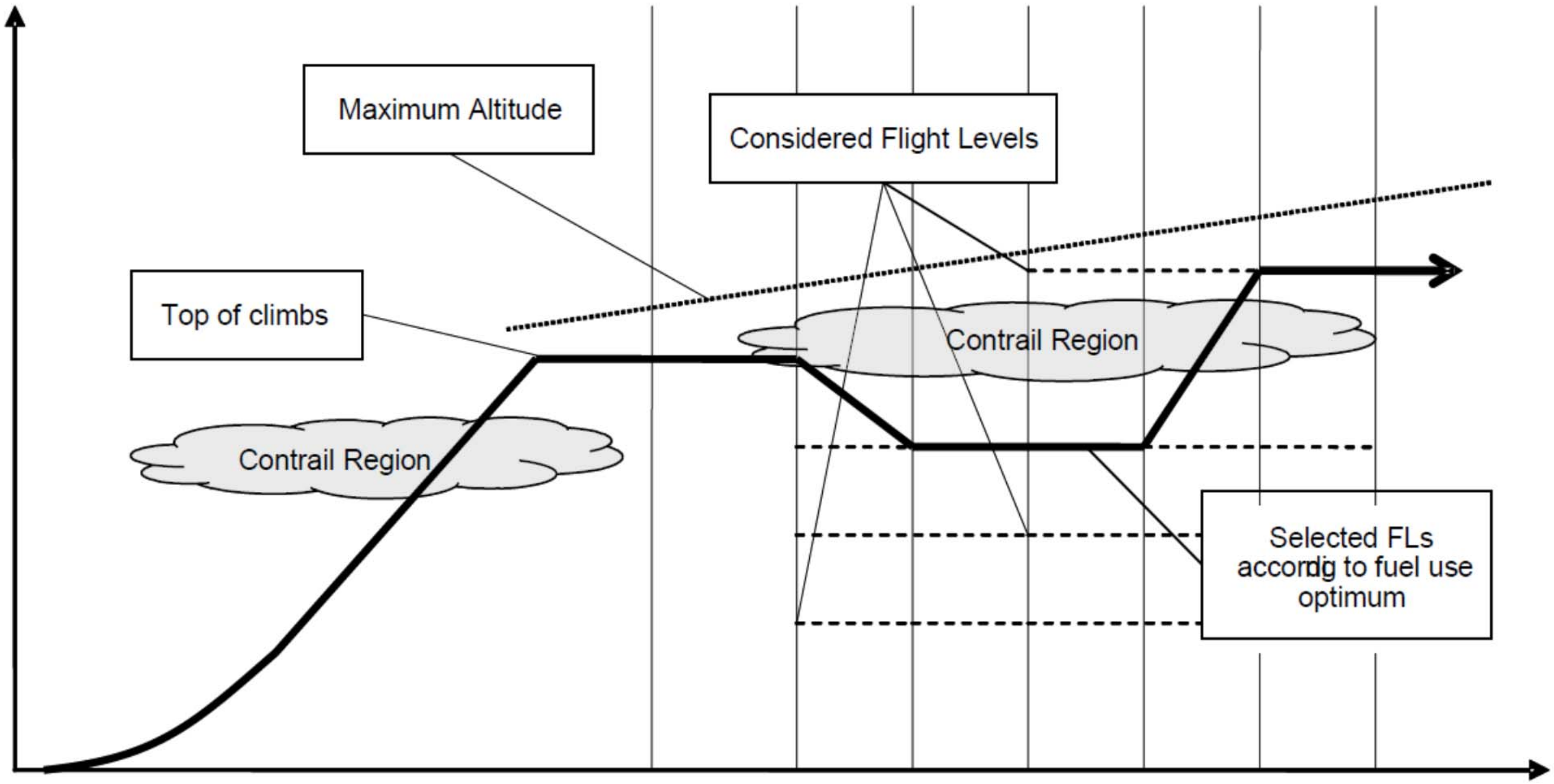
- Aviation climate impact may be reduced by cooling contrails
- Contrail-cirrus is understood and predictable to some degree
- Why not start gathering experiences in practice?

DLR

Global mean radiative forcing from contrail cirrus

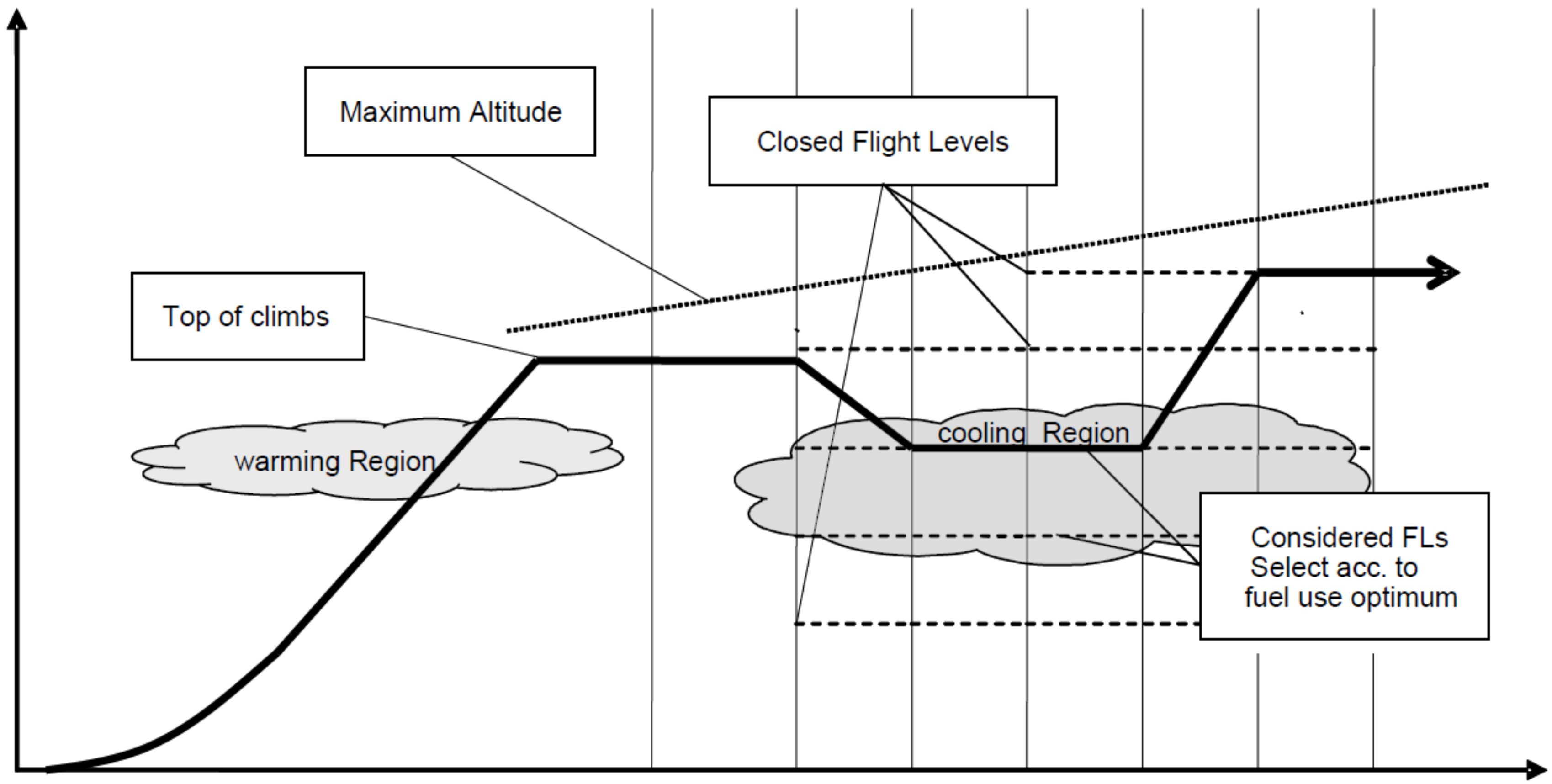


Route optimisation: avoid contrails
- by vertical and lateral route changes -



Mannstein et al.

Better: prefer cooling contrails



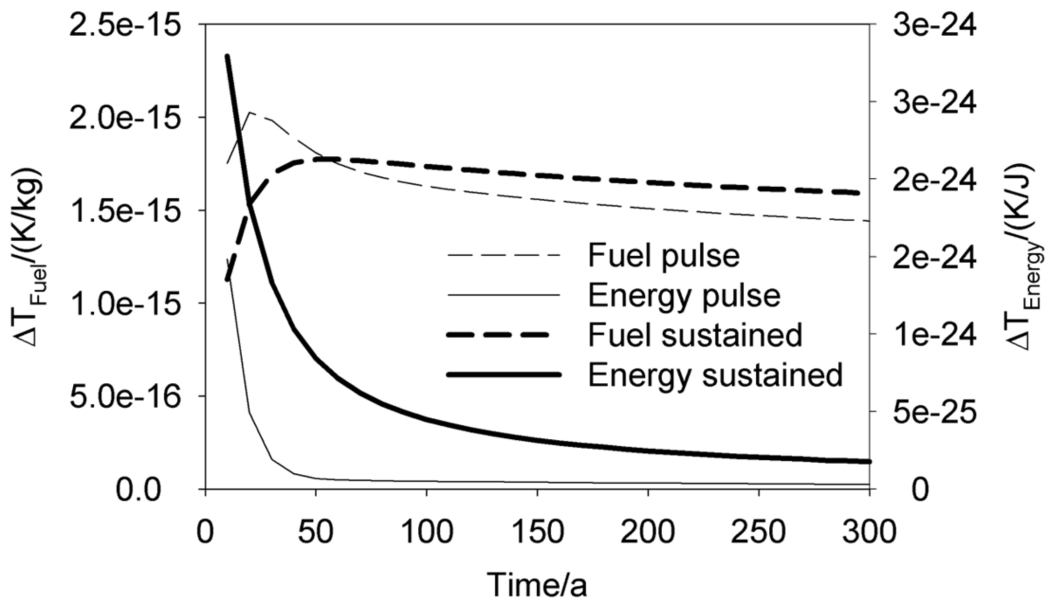
Mannstein et al.

Relevant forcing scales

- CO_2 warms: sustained air traffic with 5 kg/km fuel consumption warms at a rate of about 10^{-14} K/km for 50 years time horizon
- Sustained heat input (energy forcing, EF) by 10 GJ/km warms at the same rate over this time horizon
- A contrail, if forming, of 1 km width, 1000 s lifetime and 10 W/m^2 RF induces an energy forcing (EF) of 10 GJ/km

$$\mathrm{EF} = \int_{\mathrm{lifetime}} \mathrm{RF}(t,s) \cdot W(t,s)\,dt$$

- Hence: we have to know/predict occurrence, width, lifetime and radiative forcing from the contrails caused by air traffic

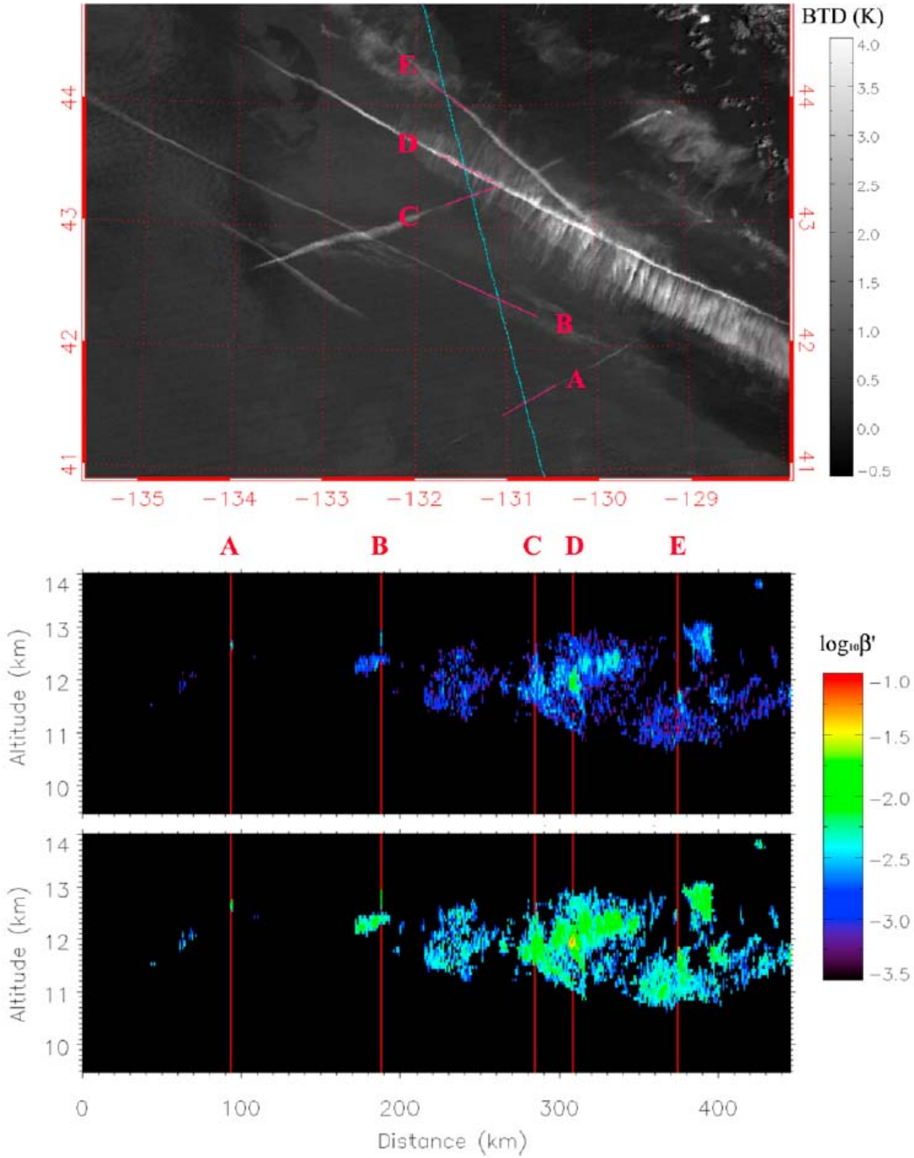


Fuglestvedt et al. (Atm. Env., 2010),
Schumann et al., (AIAA, 2011)

New insight on contrail properties from recent remote sensing and coupled climate-contrail studies:

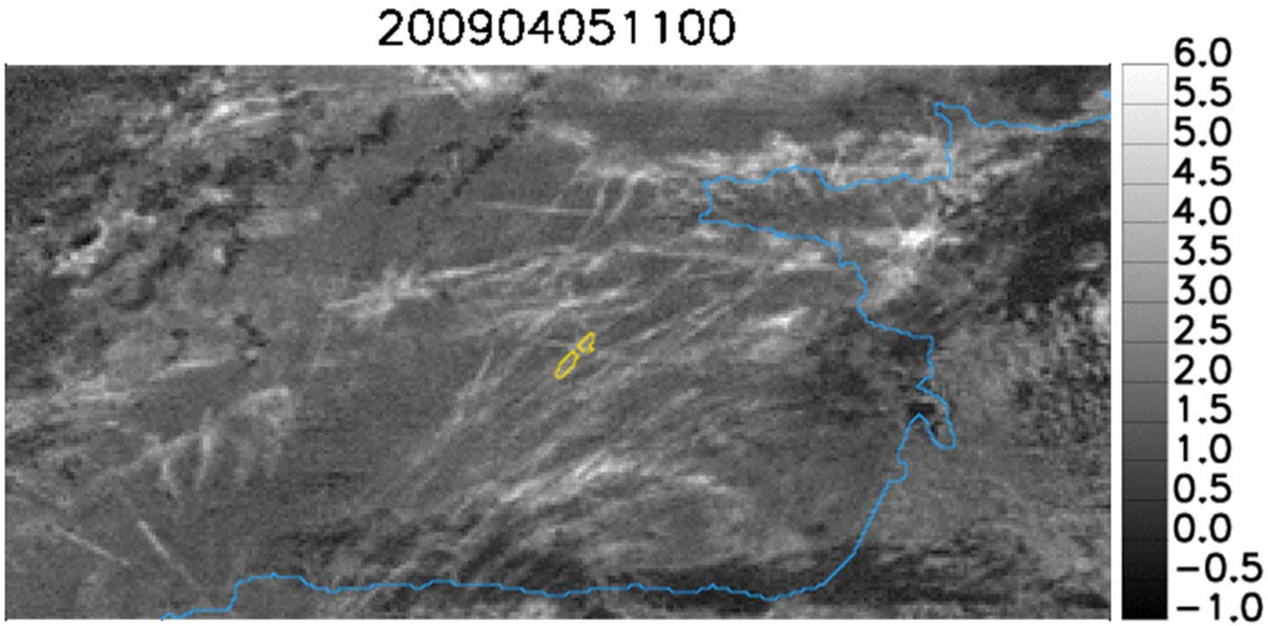
1) Iwabuchi, Yang, Liou, and Minnis (JGR, 2012)

Properties of ~3400 contrails (including width and optical depth) from a combination of satellite images (MODIS) and Lidar (CALIPSO) observations



New insight on contrail properties from recent remote sensing and coupled climate-contrail studies:

2) Vázquez-Navarro, Mannstein and Kox (ACP, 2015)



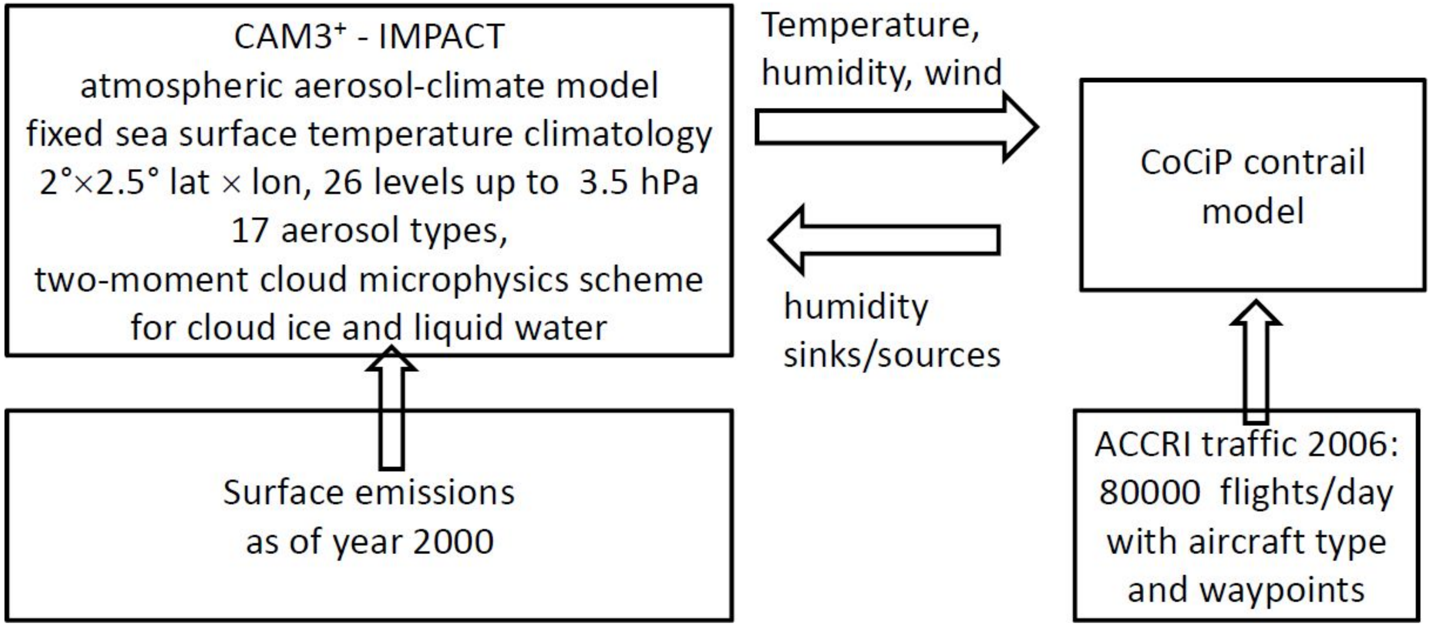
Properties of 2400 contrails observed each at various ages in subsequent Meteosat scenes

including RF and EF values

New insight on contrail properties from recent remote sensing and coupled climate-contrail studies:

3) Schumann, Penner et al. (ACP, 2015):

local and global contrail properties in a coupled climate-contrail model simulating each individual aircraft flight for 80000 flights per day over 30 years, including dehydration effects, in fair agreement with observations

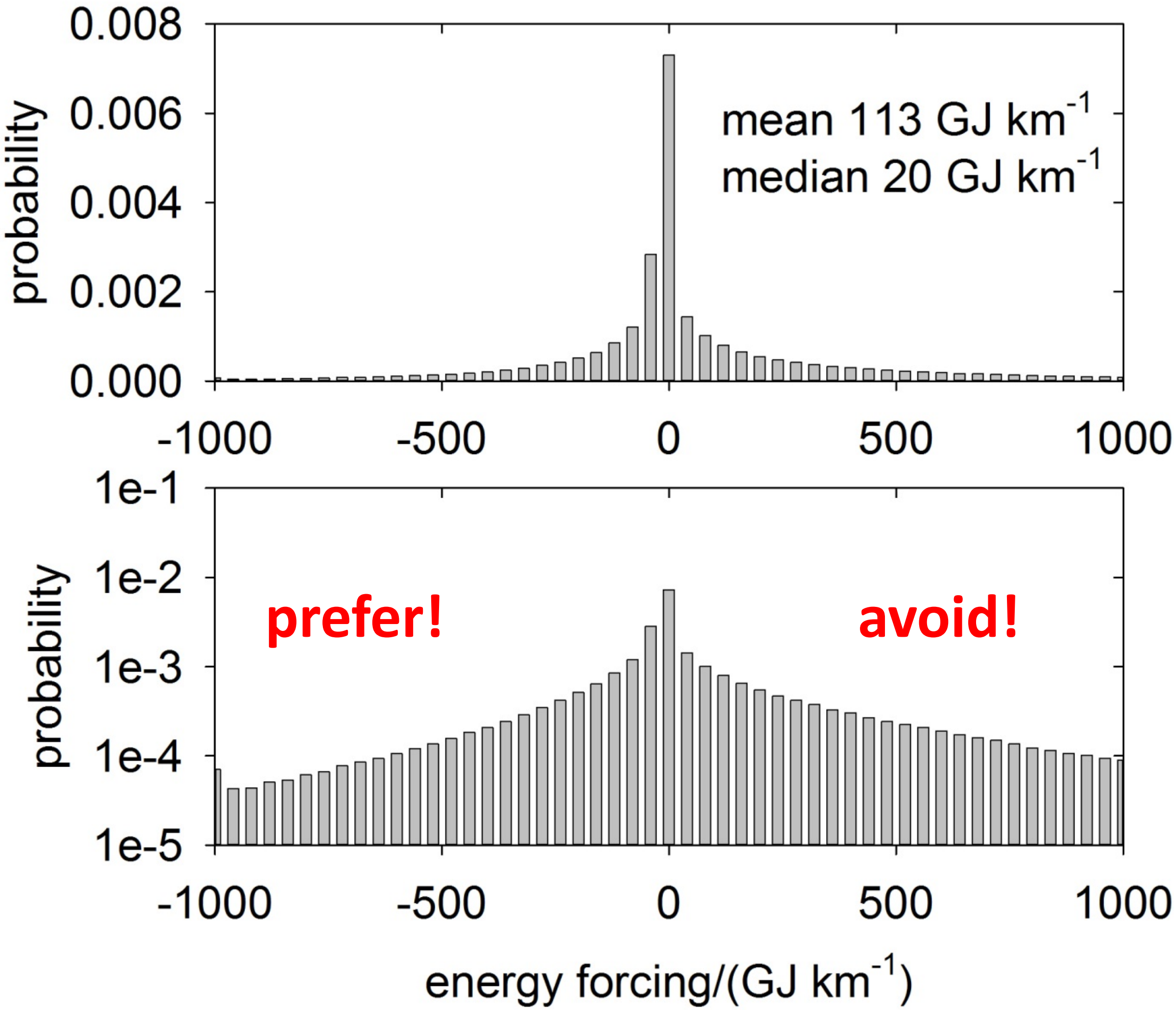


Energy forcing (EF): positive mean, highly variable

$$\mathrm{EF} = \int_{\text{lifetime}} \mathrm{RF}(t,s) \cdot W(t,s)\,dt$$

linear

logarithmic



Based on coupled contrail-climate model simulation data (Schumann, Penner et al., ACP, 2015)

Model and observation: local RF by contrails

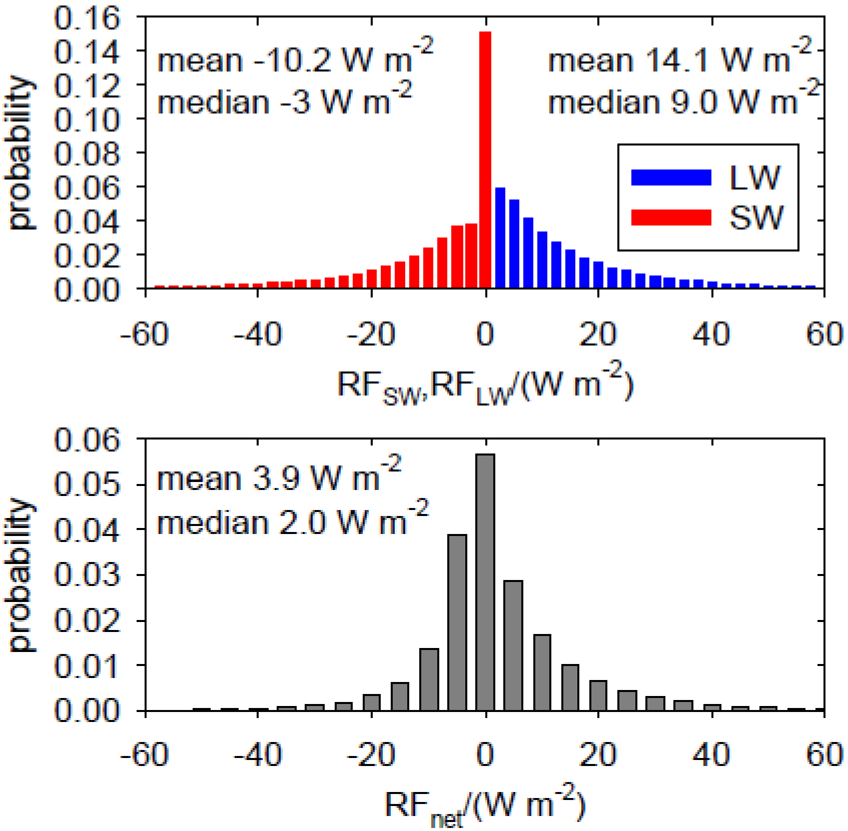


Figure 3. Pdf of local radiative forcing by contrails in the shortwave (red) and longwave (blue) ranges (top) and net RF (bottom).

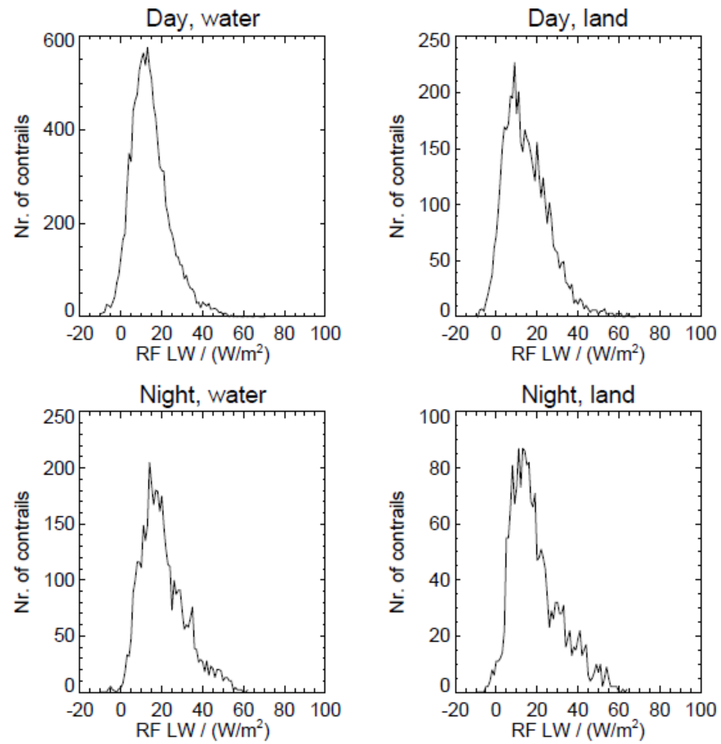


Figure 9. Frequency of occurrence of LW radiative forcing for the tracked contrails.

Schumann, Penner et al., (ACP, 2015) and

Vazquez-Navarro et al. (ACP, 2015)

Observation and Model: Lifetime: 2 h

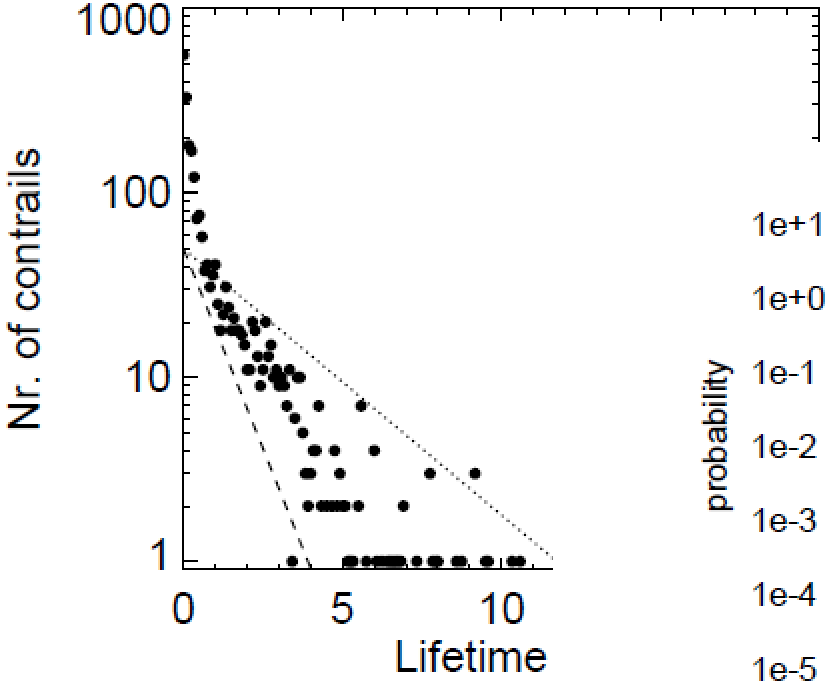


Figure 6. Lifetimes of the contrails studi
time 3 h. Dotted line: *e*-folding time 1 h.

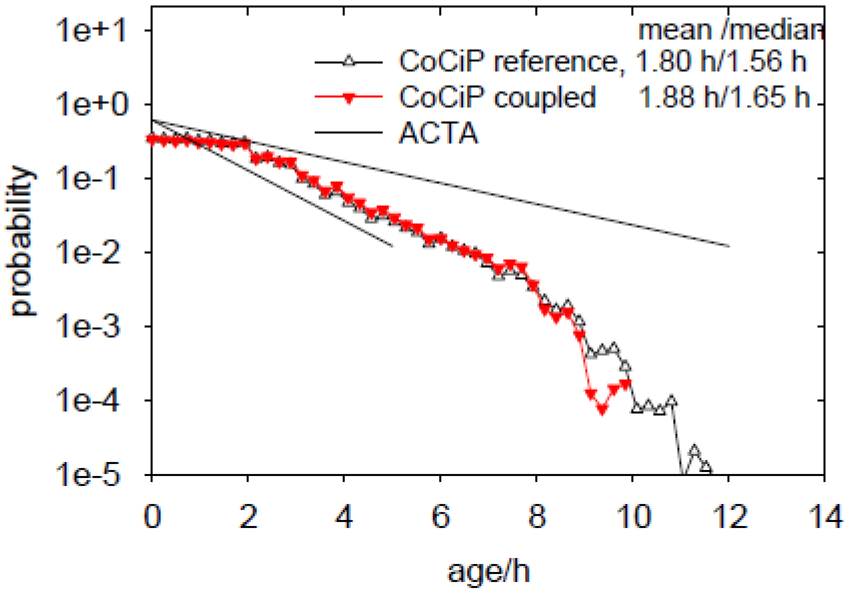
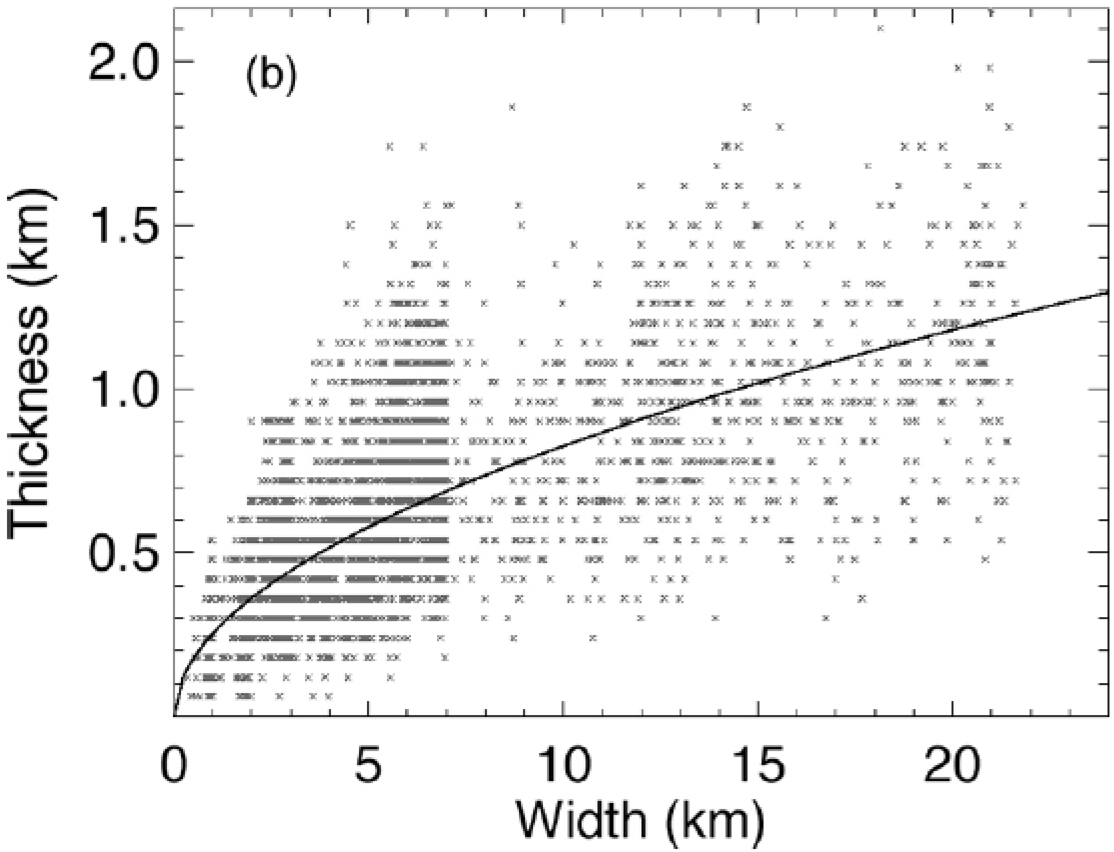


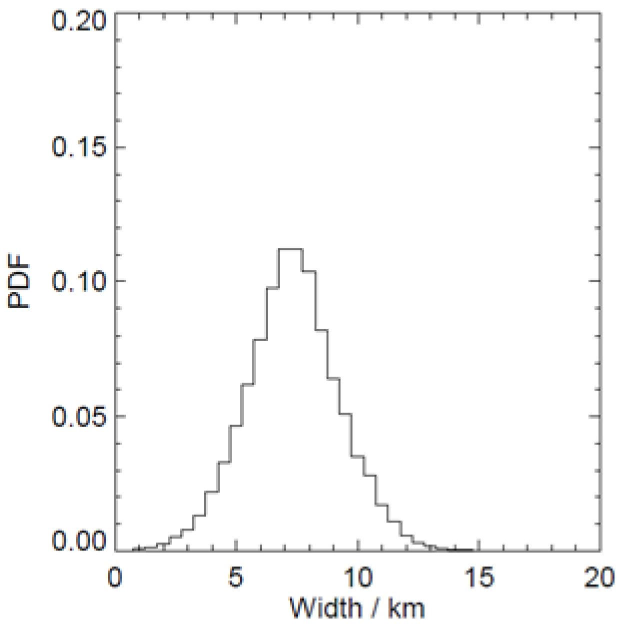
Figure 4. Pdf of contrail ages. Symbols for CoCiP runs 0 and 1 (significant below ages of about 8 h), with given mean or median values. The straight lines enclose age results for contrails tracked with the ACTA algorithm in infrared Meteosat data (Vázquez-Navarro et al., 2015).

trails. Mean values here retrieved are duration, 1 h; length, 130 km; width, 8 km; altitude, 11.7 km; optical thickness, 0.34. Radiative forcing and energy forcing are shown for land/water backgrounds in day/night situations.

Vazquez-Navarro et al., (ACP, 2015) and Schumann, Penner et al., (2015)

width: mean 10 km





Iwabuchi et al. (JGR, 2012)

Vazquez-Navarro et al. (ACP, 2015)

Energy forcing (EF) of order 300 GJ/km

$$\mathrm{EF} = \int_{\text{lifetime}} \mathrm{RF}(t,s) \cdot W(t,s)dt$$

(Schumann et al., 2012)

Table 1. Radiative day- and nighttime forcing of the tracked contrails (median values). In percent, the fraction of contrails in each case.

	Daytime RF ($\mathrm{W\,m^{-2}}$)				Nighttime RF ($\mathrm{W\,m^{-2}}$)			
	LW	SW	Net	Frac.	LW	SW	Net	Frac.
Land	13.75	−26.91	−13.16	19.0 %	16.89	0	16.89	7.8 %
Water	13.53	−28.68	−15.15	45.0 %	19.12	0	19.12	16.3 %

Table 2. Day- and nighttime energy forcing. In percent, the fraction of contrails in each case.

	Daytime EF ($\mathrm{GJ\,km^{-1}}$)				Nighttime EF ($\mathrm{GJ\,km^{-1}}$)			
	LW	SW	Net	Frac.	LW	SW	Net	Frac.
Land	267.87	−610.02	−342.15	18.7 %	269.83	0	269.83	11.3 %
Water	290.30	−875.23	−584.93	48.6 %	403.04	0	403.04	21.3 %

prefer! **avoid!**

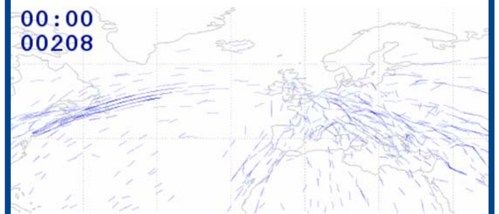
Vazquez-Navarro et al. (ACP, 2015)

Contrail Cirrus Simulation and Prediction Model (CoCiP) for assessing EF from contrails along various routes

Input:

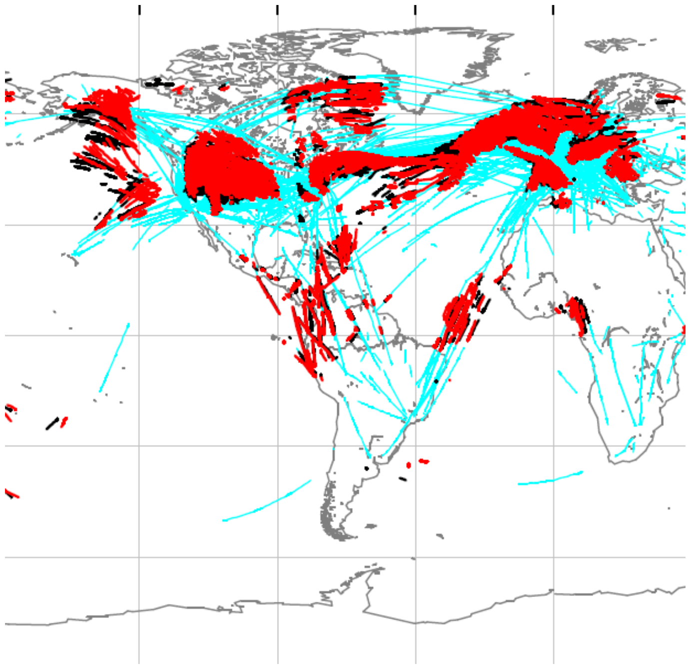
Aircraft (BADA)

Movements (historic or predicted)



Meteorology (ECMWF)

Contrail Cirrus Prediction Tool



- From regional to global
- Comparable to observations

Output:

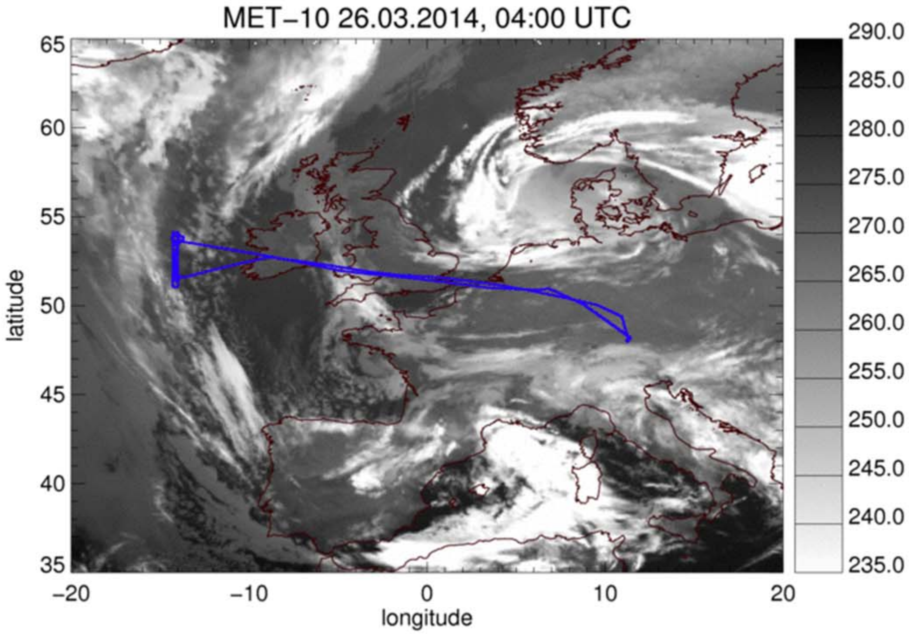
Maps of contrail cirrus occurrence (optical depth)

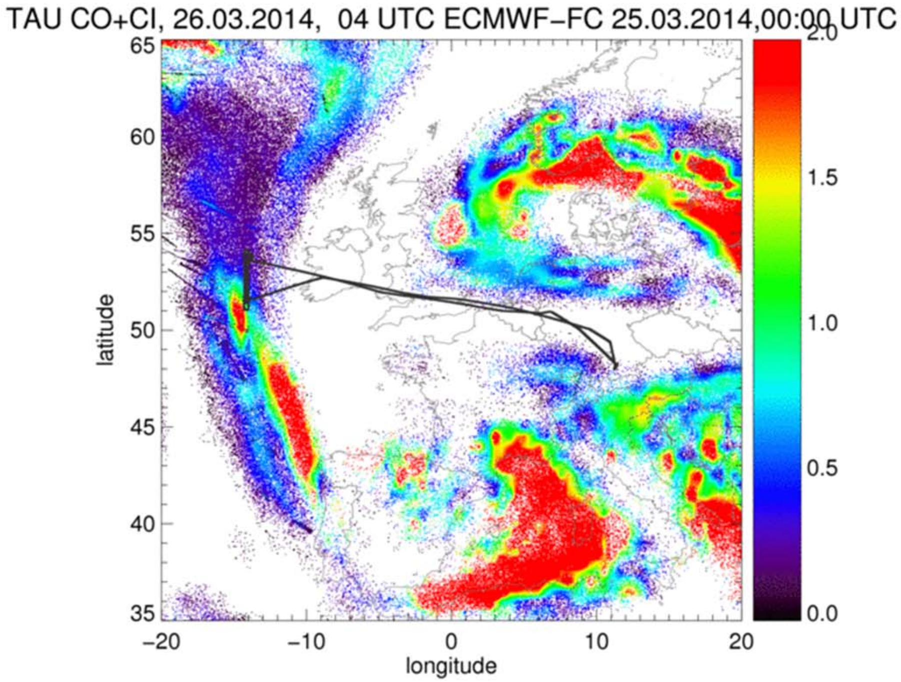
energy forcing in the integral along a set of alternative routes

(Schumann, 2012)

Contrails predicted for first ML-CIRRUS science mission

26 March 2014: North Atlantic within Shannon Radar Control Zone





EUMETSAT
Meteosat SEVIRI IR
Brightness temperature at 10.8 µm
Blue: HALO flight path

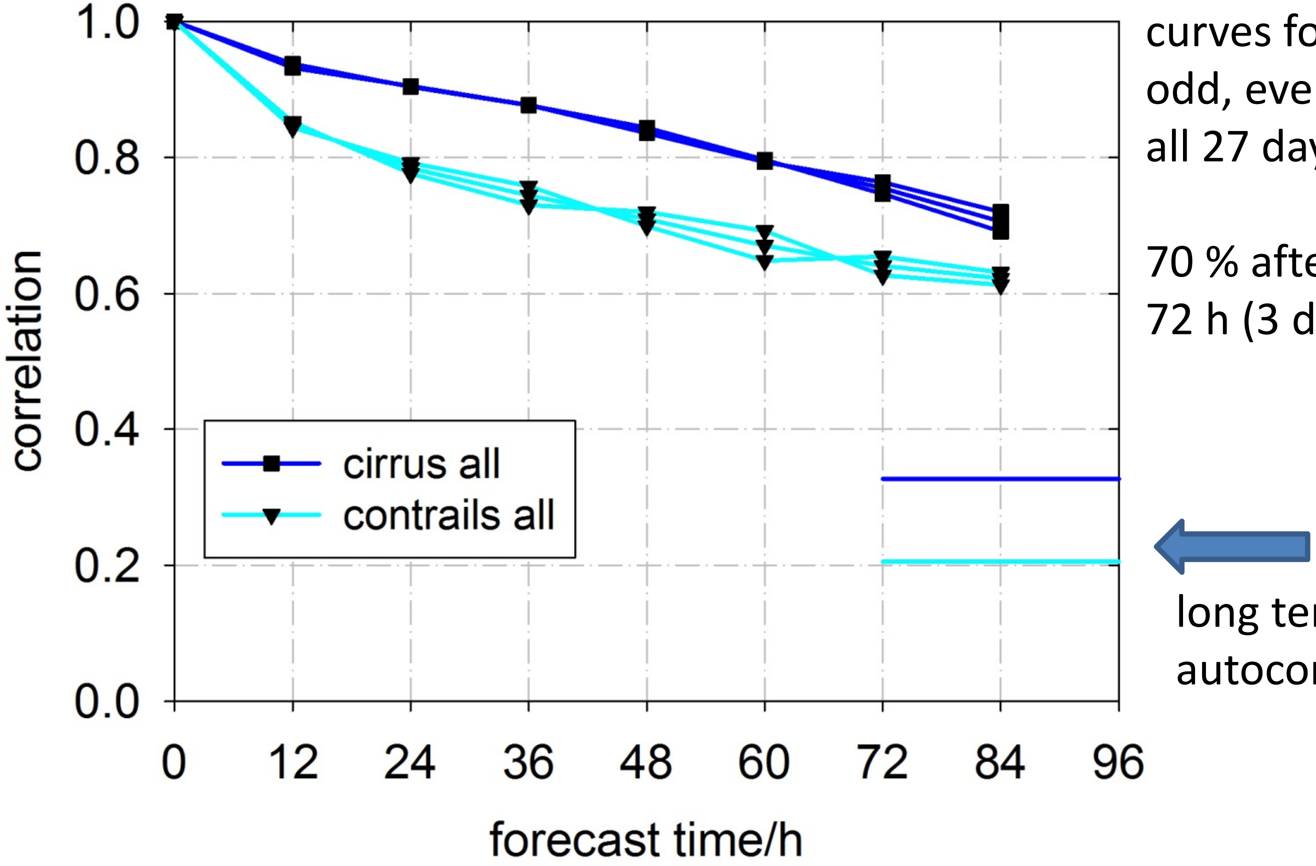
CoCiP with ECMWF and ACCRI data:
optical depth of contrails+cirrus
Blue: HALO flight path

Schumann et al. (TAC4, 2015)

Quantification of forecast skill for 27 days: Autocorrelation of optical depth predictions versus forecast time interval

$r(\Delta t) = \langle \tau'(t_s, t_s+\Delta t)\ \tau'(t_s, t_s) \rangle / \langle \tau'(t_s, t_s)^2 \rangle^{1/2}$, with $\tau' = \tau - \langle\tau\rangle$

$\langle .. \rangle$: average over all 1°×1° grid cells



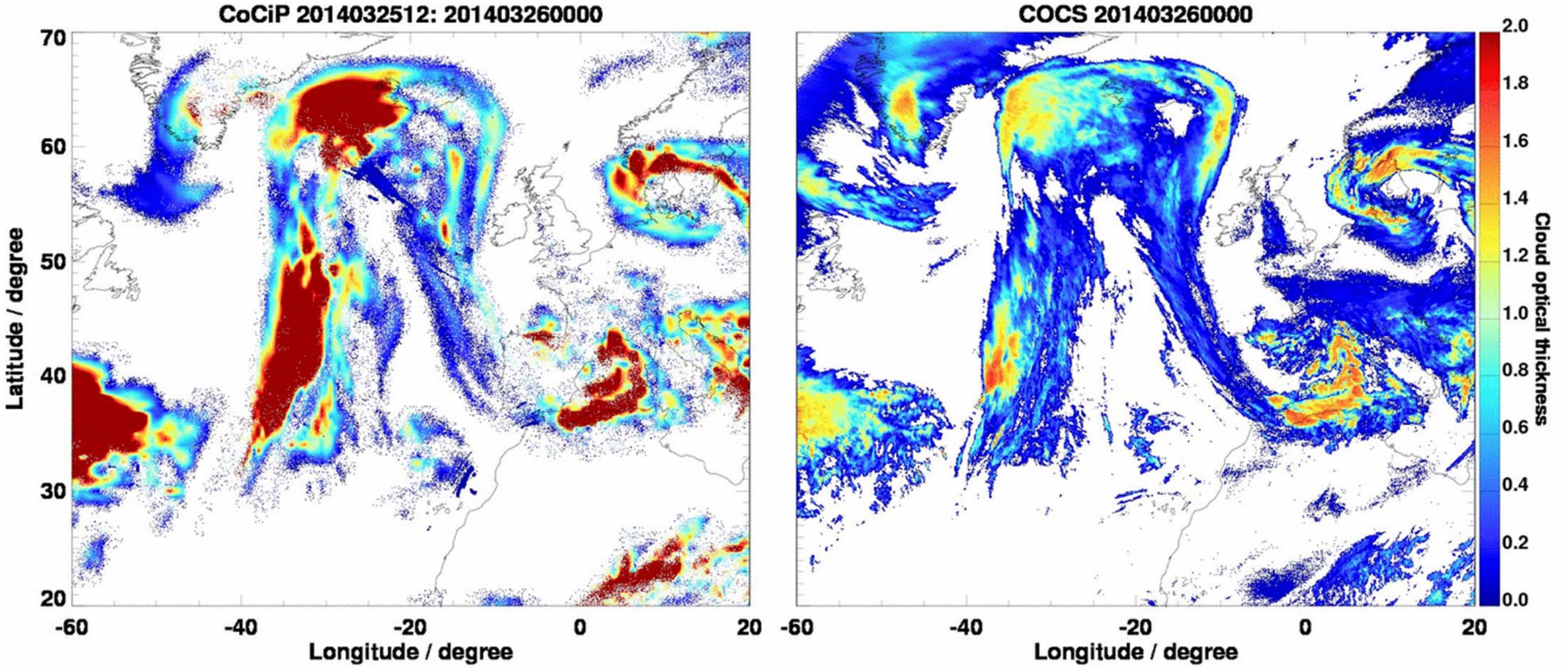
curves for odd, even and all 27 days

70 % after 72 h (3 days)

long term autocorrelation

Schumann, Graf et al. (TAC-4, 2015)

Predicted and observed optical thickness (Meteosat-COCS)



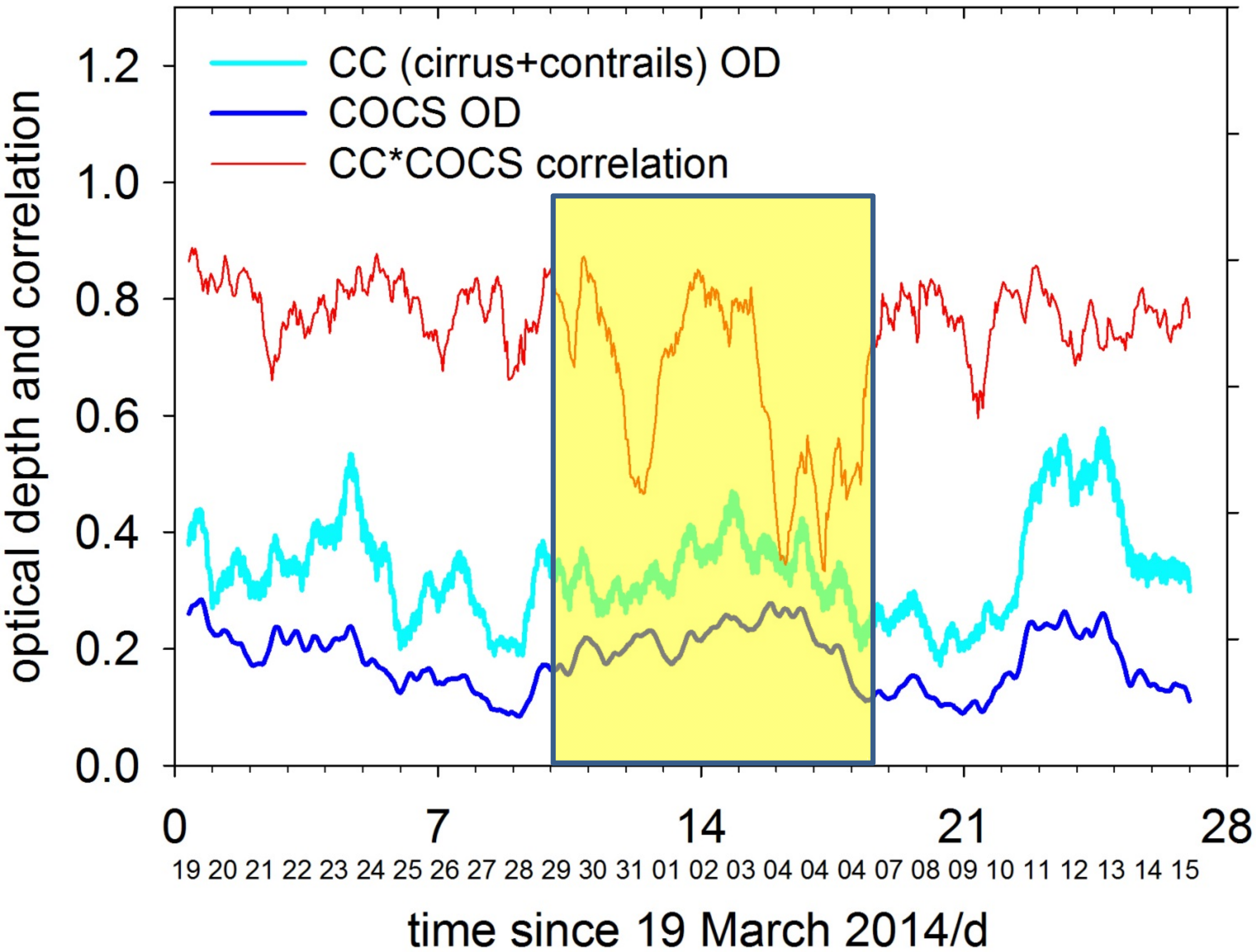
Optical depth of contrails + cirrus from CoCiP/ECMWF during ML-CIRRUS

(K. Graf and U. Schumann)

Optical depth of thin cirrus derived from METEOSAT SEVIRI IR data using the COCS algorithm (Kox, 2014),
Data processed and plotted by L. Bugliaro, 2015

Correlation between forecast and observations

$r = \langle \tau'_{cocip}\, \tau'_{COCS} \rangle / \langle (\tau'_{cocip})^2 (\tau'_{COCS})^2 \rangle^{1/2}$, with $\tau' = \tau - \langle\tau\rangle$,
on average over all 1°×1° grid cells



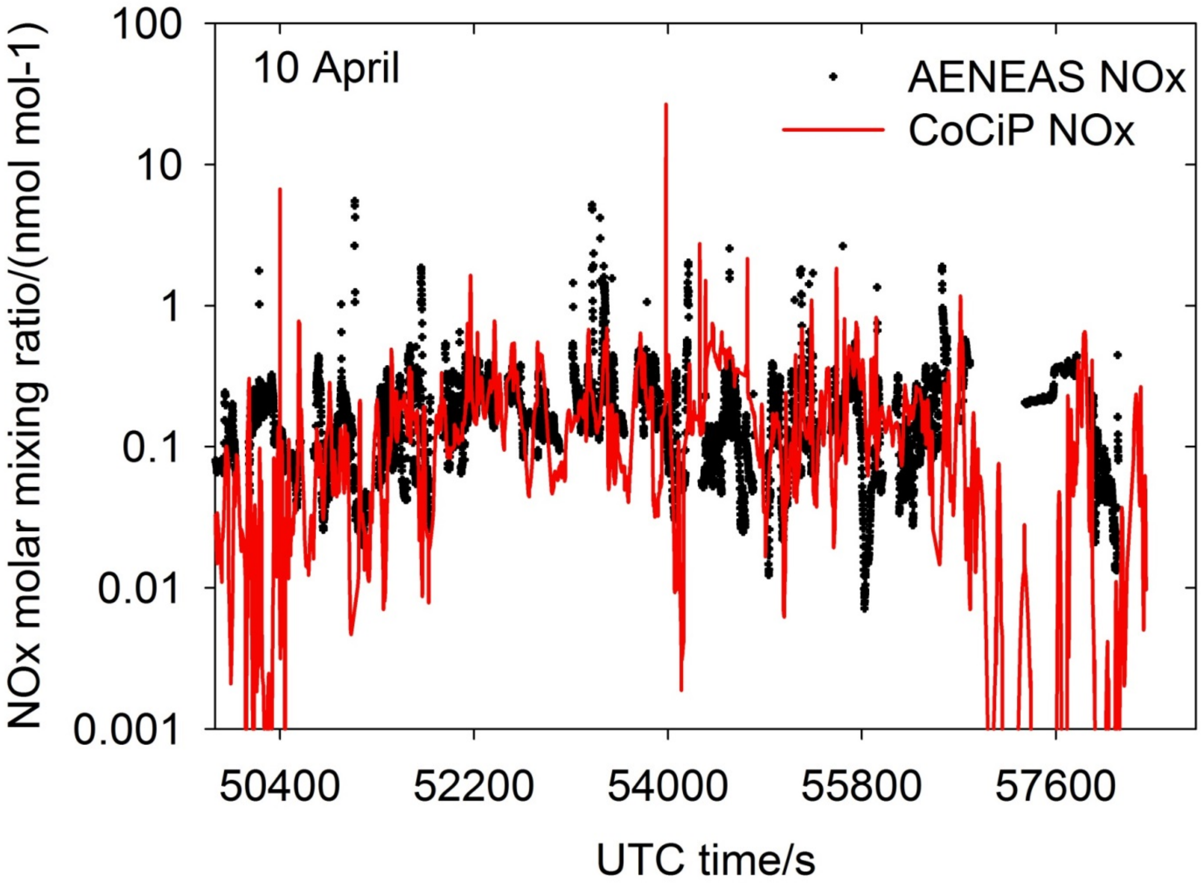
Schumann, Graf, Bugliaro et al. (TAC-4, 2015)

dust period
29.3. -7.4.

r= 70-90 %
outside dust
period

10 April: NOx-Plume tracer comparison: measure for how good CoCiP simulates plume dilution

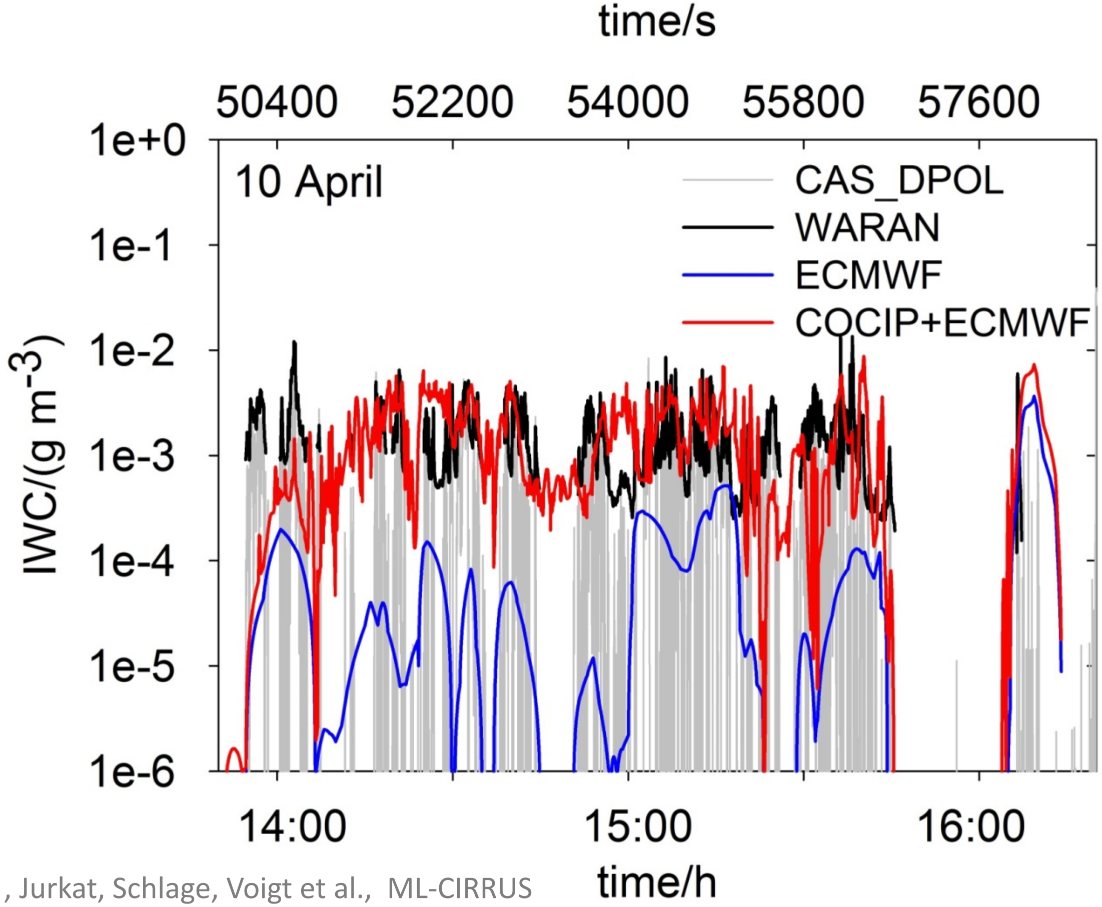
Black: NOx data deduced from measured NO, O_3 and T, and from estimated photolysis rates.: Red: computed from passive tracer aircraft emissions during last 24 hours (assumed NO_2 EI: 20 g/kg).



Schumann, Ziereis, Zahn (KIT) et al., ML-CIRRUS

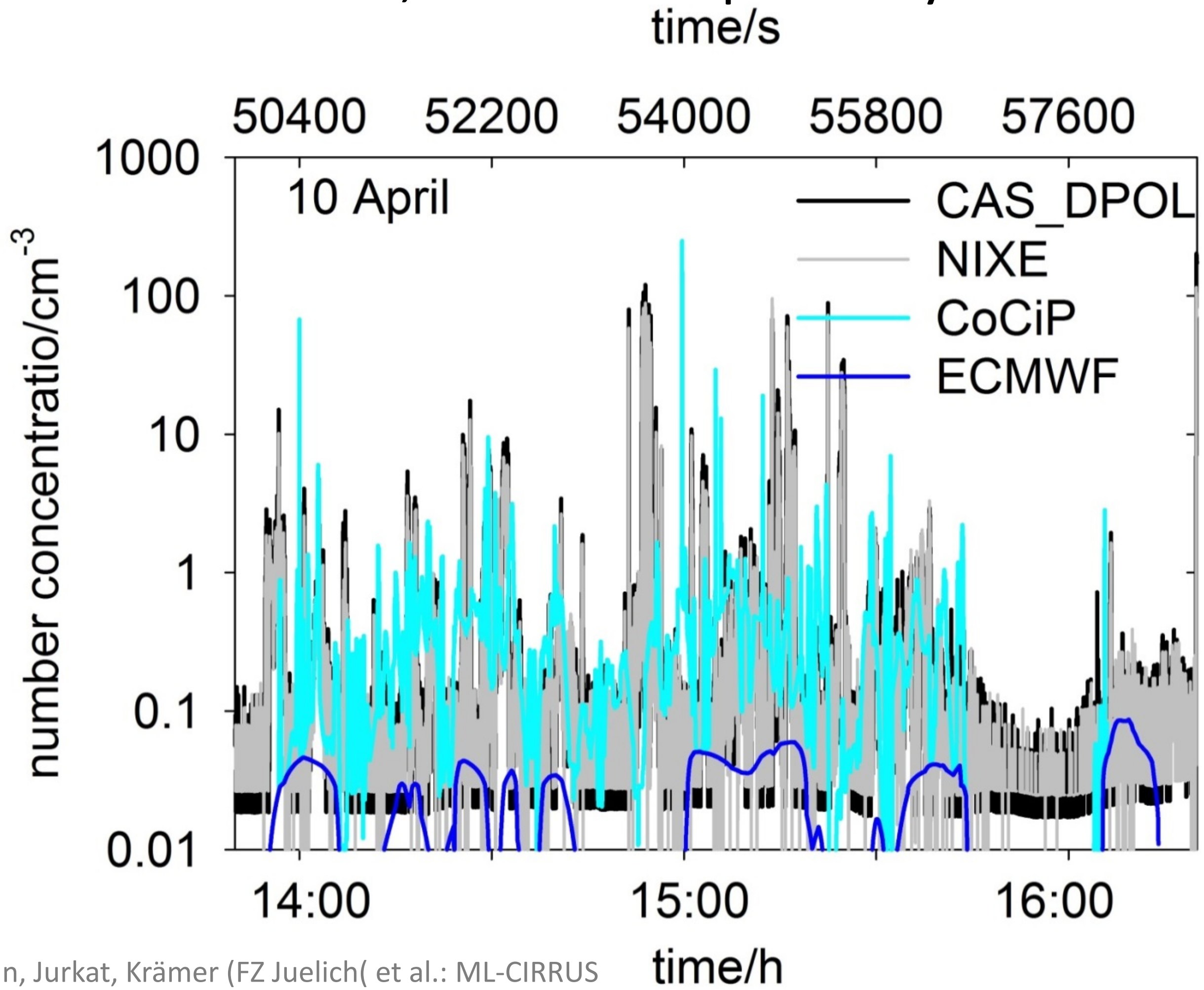
10 April: Measured IWC mainly from contrails

Ice water content (IWC) deduced from ice particle size spectra CAS-DPOL data (~0.5-50 µm), from WARAN (difference between measured humidity and saturation), from ECMWF forecasts, and from CoCiP model. Note: measured IWC mainly from contrails in this case.



10 April: Measured ice particle number concentration mainly from contrails

Number concentration of ice particles as measured by CAS-DPOL and NIXE (both ~0.5-50 µm; preliminary data), as derived from ECMWF IWC and temperature forecast, and as computed by CoCiP.



Schumann, Jurkat, Krämer (FZ Juelich(et al.: ML-CIRRUS

Conclusions

- Contrails warm globally, but may cool locally
- Routes with high fraction of cooling contrails (or no contrails) reduce climate impact of aviation
- Because of high forcing variability: Small route changes have large mitigation potential
- Good predictions require good weather (humidity), route, and fuel consumption prediction
- Contrail cirrus is predictable now (about 70-80 % autocorrelation after 3 days at 1°-spatial and 1-h-time scales)
- Further research required, but:
- Prediction accuracy sufficient to start implementing climate route optimization for practice now.

DLR